John T. Anderson

Engineering Note

Date: February 22, 1999
Rev Date: March 4, 1999

Project: CFT Axial Non-Handed Board
Doc. No: A990223A

Subject: Cryostat Temperature Monitoring and Control in the Non-Handed Board

Introduction

One of the many features of the CFT Front End board is that it must provide bias current to, and resistance measurement of, a sense resistor buried in the helium-chilled section of the cassette. This temperature measurement must be presented both to an external connector and to the internal microcontroller to allow either an external PLC system or the local microcontroller to control the VLPC temperature. When the microcontroller is the loop controller, it must provide measurement of the cryostat temperature to the experiment slow monitoring system at regular intervals, plus fault detection.

Measurement of the cryostat temperature is obtained using the nonlinear resistance changes which occur within a carbon composition resistor at cryogenic temperatures. Control of the temperature is obtained by manipulating a bleed current to a heater resistor which has a much smaller temperature coefficient. When either the PLC or the local microcontroller is used, a lookup table is employed to relate the measured resistance to a temperature, and the temperature to the resistance of the heater, which then is used to calculate the required current change in the heater. Since the relationship between temperature and resistance in both has a consistent sign of slope, even though the slope of the resistance change with temperature is a function of the temperature, a simple closed-loop response will always converge or oscillate around a setpoint. So long as the step sizes are small, and the time constant of response fairly large to limit the range of oscillations, a simple proportional response system is sufficient. If some integration is required, simple averaging should suffice.

Temperature Sensor Resistor

Previous inquiries into this problem have led to the selection of a carbon composition resistor for use in the VLPC cassette. A typical response, taken from an older D-zero paper, is shown in Table 1.

Temperature, degrees K	Resistance, ohms
1.257	35402
1.527	16448.03
2.083	5829.75
2.597	3123
3.849	1171.47
4.138	1026.18
5.006	747.98
6.048	571.52
7.036	472
8.071	404.72
9.154	356.05
10.095	324.77

Table 1

In the VLPC temperature region of interest, the resistance ranges anywhere from a couple of hundred ohms up to a little more than 1000 ohms. In order to measure this resistance, a fairly small current must be used, or self-heating of the resistor will obscure the measurement. Communication with Russ Rucinski suggests that the excitation current of the sensor should be no more than 10 uA. With a sensor excitation current of 10 uA, the power dissipated in the resistor will be on the order of

$$P = I^2 R = (10e-6)(10e-6)(1e3) = 100e-9 = 0.1uW$$

which is certainly not enough to bias the measurement significantly. This sense current must be maintained while the resistance is varying with temperature, so a constant-current source is called for. The Analog Devices AD620 differential amplifier and the Analog Devices OP295/OP495 op-amp are already in use elsewhere in the board, and so are a logical choice for deriving the constant current source. The data sheet for the AD620 gives a nice circuit for a constant-current source, shown as Figure 1. Eight copies of this circuit (one per VLPC cable) are implemented on the front end board.

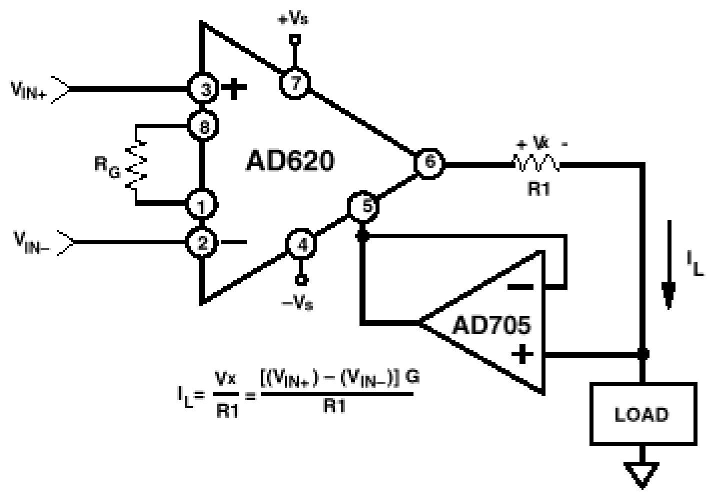

Figure 1

Circuit Analysis

To obtain an excitation current of 10 uA, R_g is set infinite (open circuit), to place the gain of the AD620 at 1.0. R_1 is a 0.1% precision resistor of 10.0K ohms, so the input differential V_x becomes 1 volt. The AD705 is shown in the application data because it's input bias current is less than 1 nA; the OP295/OP495 maximum bias is listed at 30nA, which will result in a less than 0.1% error in the desired current, and is acceptable for this application. The offset voltage of the OP295/OP495 is less than 800uV, which is also less than 0.2% of the voltage drop expected across R_1.

Another instance of the AD620 may be used to measure the voltage dropped across the temperature sense resistor. With the resistance expected to vary between 100 and, say, 5000 ohms over all useful temperatures, the voltage dropped across the resistor will range from 1mV to 50mV. With a gain set to 100, the output will range from a minimum of 0.1 volt to 5 volts, well suited to the A/D converter of the local microcontroller or an external PLC. Since the AD620 will be powered from a ±12V supply, clip diodes should be implemented on the output to insure that the AD620's output does not exceed the maximum input voltage to the A/D converter, or go too far below ground during faults. At the assumed operational temperatures of the VLPC (around 6-7 degrees K) the slope of the resistor is about 100 ohms per degree K, corresponding to an output voltage change (at gain = 100) of about 2500 mV per degree K. A 5-volt, 12-bit A/D has an LSB resolution of about 1.2mV per LSB; throw away the low two bits as noise, and the system still can measure differentials of ±0.002 Kelvin.

Despite the precision with which temperature *differentials* can be measured, however, the precision of the *absolute* temperature measurement is dominated by the accuracy of the current source, which will be no better than the 0.1% tolerance of the 10.0K ohm precision resistor; at an operating temperature of 9 Kelvin, ±0.1% is ±.009 Kelvin. Variance between the sense resistors from one cassette to the next, and in the resistor setting the gain of the AD620, may easily double that error. Therefore, assuming the cryostat to be ideal, the temperature won't be *known* to better than a few tens of milliKelvins. Verbal feedback from Stefan indicates that the target design is to *maintain* the temperature to ±0.001 Kelvin. E-mail input from Russ Rucinski, however, indicates that the cryostat itself won't be stable to better than ±0.050 Kelvin. Putting it all together, the VLPC temperature can probably be *maintained* to no better than ±0.075 Kelvin after all errors are accounted for. A schematic of the full on-board temperature sensor is given in Figure 2.

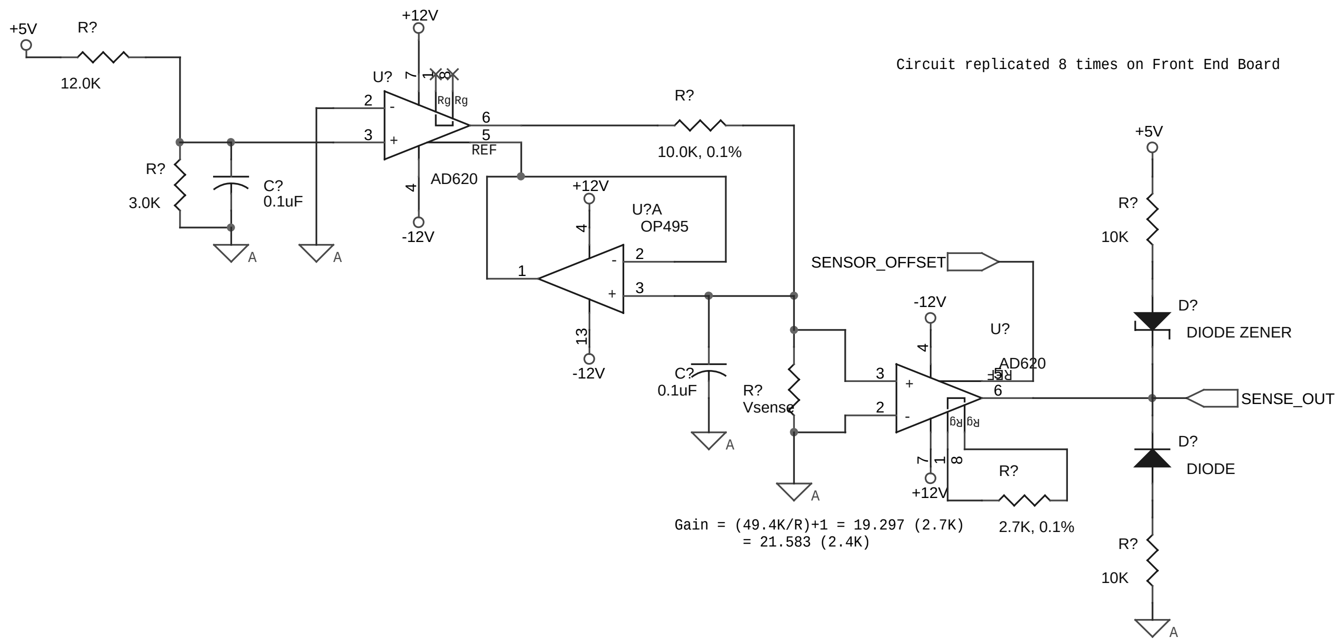

Figure 2

Cryostat Heater Control

An earilier engineering note (#a980916a) points out that a zero to 10 volt voltage source is required to drive up to 20 mA through a 500 ohm heater resistor. The OP295/495 can only deliver up to 15 mA, so another op-amp is called for. The OP279 high current buffer is a reasonable choice. Using the OP279, the zero to +5 volt output of a DAC is buffered with a gain of two to create a zero to +10V output. This is driven through the 500 ohm heater resistor. Four copies of this circuit are required per board, as the OP279 is a dual buffer. One copy is shown as Figure 3. An eight-bit DAC is used to drive the op-amp, resulting in 256 different levels of heat applied.

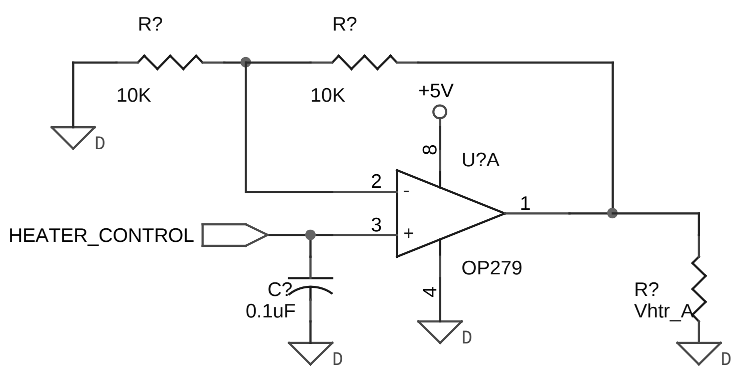

Figure 3

Internal vs. External Sense and Control

Safety issues will crop up if voltages in the system exceed 50 volts. With a desired maximum current of 20 mA per heater resistor, and a resistance of 500 ohms, the voltage drop across a heater may be as high as 10 volts. When using an external PLC to drive all the heaters, they will have to be wired in series-parallel such that no more than 2000 ohms is presented to the external PLC, so that the externally applied voltage does not exceed 40 volts.

This implies some form of jumpering arrangement to allow for internal vs. external heater control. The VLPC cable provides connections to two heater resistors per cable; the simplest arrangement is to wire one heater resistor per cable to the internal control system, with a unique op-amp instance per cable. For external control, the second heater resistor of cables 1,3,5 & 7 are connected in series, and this group is connected in parallel with the series combination from cables 2,4,6 & 8. Figure 4 shows the 'external' heater hookup.

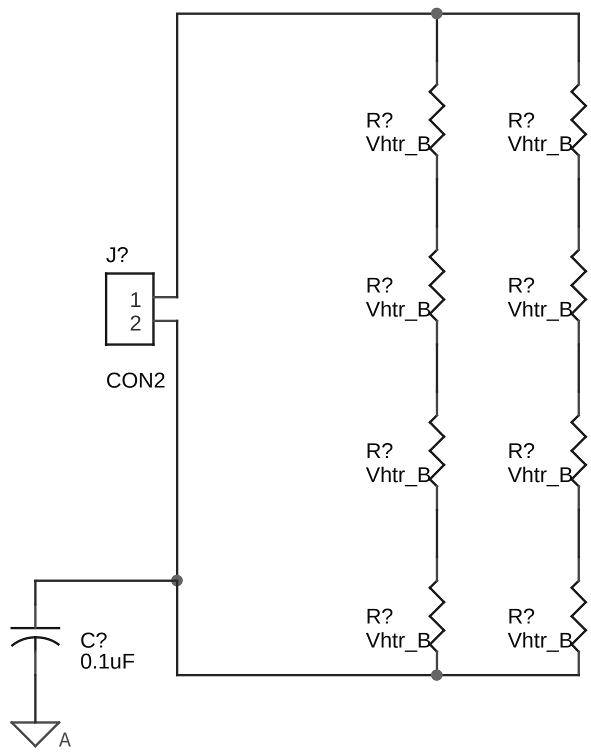

Figure 4

If the external PLC is used for control, a single 'group sense' wire is run across the board with an optional resistor connection from each temperature sensing amplifier. One of the eight cables is arbitrarily selected to act as the temperature monitor for the whole cassette and the resistor for this amplifier is connected to the 'group sense' wire. In case of a fault, one of the remaining seven may be chosen.